AN INQUIRY

INTO THE INFLUENCE OF

ANTHRACITE FIRES

UPON

HEALTH;

WITH REMARKS UPON ARTIFICIAL MOISTURE,

AND THE BEST MODES OF WARMING HOUSES.

BY

GEORGE DERBY, M. D.,

SURGEON TO THE BOSTON CITY HOSPITAL, EDITOR OF MASS. REGISTRATION REPORTS,
UNIVERSITY LECTURER ON HYGIENE IN HARVARD UNIVERSITY.

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PREFACE TO FIRST EDITION.

THE following observations upon the influence of anthracite fuel upon health were read before the "Boston Society for Medical Improvement," at their meeting on the 10th instant.

The paper is published in this form in the hope that it may contribute to a general knowledge of one of the many ways in which disease may be prevented and health may be preserved.

102 CHARLES STREET, BOSTON,
February 20, 1868.

PREFACE TO SECOND EDITION.

In preparing a new edition of this little treatise, which includes additional information collected and arranged during the past summer, the opportunity presents itself for giving a brief history of the investigation.

The original paper, prepared for a medical society, had two objects:

1st, an attempt to explain the definite cause of the singular effects upon health which have been found to proceed from the ordinary domestic use of hard coal.

2d, an attempt to show that the difference between an atmosphere agreeable to lungs and head, and one which is disagreeable to the whole man, does not lie in the amount of moisture which they respectively contain.

The evidence bearing upon these two points was made up in part from original observation, and it now appears substantially in the first forty-four pages of the present volume. To this was appended a few words relative to the different modes of heating in common use, and the management of hot-air furnaces.

The paper in this form was first read to Dr. John Bacon, Professor of Chemistry in Harvard University, who kindly consented to note any chemical inaccuracies which might have been committed. Dr. Bacon suggested that perhaps additional proof might be

found in the record of certain experiments upon the permeability of iron at high temperatures by gases, made in 1863 and 1864 by Deville and Troost, and referred to in the last edition of Brande's Chemistry.

From this suggestion the authorities were looked up; the passage through certain metals of carbonic oxide, among other gases, was found to be clearly demonstrated; and the application of this important fact was made, seemingly for the first time, to the passage of the products of combustion through the walls of cast iron stoves; and thus appended to the original essay.

After the publication of the first edition, it appeared that this obvious application had been made in the same month in Paris.

Dr. Carret of Chambery reported in 1865 that the substitution of cast iron for porcelain stoves had produced, within his own knowledge, serious effects upon public health. No attention seems to have been given to this communication until the application of the observation of Carret to the remarkable discovery of the porosity of cast iron by Deville and Troost, was made by General Morin, January 13, 1868, as appears from the published proceedings of the French Academy.

This statement is now made as adding proof of the correctness of some of the opinions expressed in the following pages, since the observations at Boston in 1868, were made without any knowledge of those at Chambery in 1865; in so far as cast iron stoves are concerned, both lead to similar conclusions; and both become more intelligible in the light of the experiments of the French chemists, and of Professor Graham. The communications of General Morin and M. M. Deville and Troost, are now reprinted in the Appendix. General Morin is the present Director of the "Conservatoire des Arts et Metiers,"

and the highest authority in France on the subject of ventilation.

It is to be hoped that the influence of hard coal will be shown in the experiments which are now to be made by the committee of the Academy. The fuel commonly used in French stoves is bituminous coal, a far less dangerous substance in the products of its combustion than our anthracite.

In the present treatise the important subject of ventilation has been referred to only when its connection with the matter in hand was so intimate that it could not be avoided.

BOSTON, October 20, 1868.

ANTHRACITE AND HEALTH.

PART I.

Sixty years ago anthracite coal was regarded all over the world as incombustible refuse. Its use in America dates from the period when supplies of English coal for the manufacturers of the Middle States were cut off by the war of 1812. Attention was then drawn to the anthracite deposits in Pennsylvania, and many vain attempts were made to use them.

These efforts were finally successful; and within ten years, or about 1820, the use of hard coal for manufacturing purposes became general. It was not, however, until about 1830 that it began to be employed for warming houses, and still later for cooking. Recently it has become the fuel generally used for both these purposes.

There has always, however, been a minority of persons who have disliked it in their houses, who have resisted its introduction in the rooms in which

they lived; and not a few who, after trial, have discarded it and substituted bituminous coal and wood.

Its great economy of labor and its heating power have been sufficient recommendations, however, to allow of its almost universal use in hot-air furnaces; and at the present time it is safe to say that ninety-nine dwelling-houses out of a hundred in Boston are, in whole or in part, warmed by this fuel burned in iron stoves, or in the iron fire-pot of a furnace which is but a stove in another form.

One object of this inquiry is to learn, if we can, whether this is conducive to health; and if injurious, why it is so.

It is a matter of common observation that different kinds of fuel give apparently different kinds of heat. Hard coal on the one hand, and soft coal and wood on the other, produce different impressions. Anthracite burning in an open grate affects, if not everybody, certainly a great majority of persons very differently from an open fire of wood.

The heat is radiant in both cases, warming the floor and the furniture and the bodies, both animate and inanimate, on which its rays fall; the temperature may be the same; the ventilation also is, or may be, perfectly good in both cases; yet the impressions, not the moral impressions affected by a beautiful fire or pleasant associations,

but the impressions upon the nervous system, are quite different.

With a certain proportion of persons who may be supposed to be more sensitive, anthracite burned in this way under the most apparently favorable circumstances causes difficult respiration, headache (often described as if an iron hoop were bound round the head), dizziness, confusion of ideas, languor, heaviness,—a group of symptoms leading to the suspicion of the presence of a narcotic poison. These unpleasant sensations are generally removed almost immediately on breathing the open air.

Many other persons, without analyzing the effects it produces, do not like a hard-coal fire, and in spite of its convenience and economy will not use it in the rooms which they occupy through the day, and burn soft coal or wood in their parlors and business-offices at twice the cost of anthracite.

The same difference may be observed in stoves burning wood or anthracite, although it is less apparent, because usually in both cases ventilation is bad, and impressions produced by foul air obscure those which proceed from fuel.

In the case of furnaces we have a fair subject of comparison between those which pass the air over and around a heated fire-pot containing anthracite, and those in which the air is conducted through coils of pipe containing either steam or

hot water, and enclosed in a confined space in the cellar or basement.

In each of these cases the air is forced into the rooms above, and ventilation may be perfectly good; the temperature may be the same; yet the impressions made by these two kinds of heated air, one proceeding from a fire-pot filled with anthracite, the other from pipes filled with steam condensing into water, or with hot water, are to many persons quite different and can be distinguished.

If further proof is needed of the reality of this difference it may be found in the action of these two kinds of heating-apparatus upon plants.

It is notoriously difficult to make the more delicate varieties flourish in houses warmed by anthracite stoves or furnaces. A gentleman conversant with plants informs the writer that experience has proved that hot-air anthracite furnaces, like those in dwelling-houses, cannot be used in greenhouses.

Where anthracite is the fuel employed, as it generally is, the fire is in a separate building and heat is communicated to the greenhouse either by hot-water pipes carried round its walls and under its floor, or by brick flues carrying the heated air with the products of combustion by a long and circuitous passage round the building; heat being thus radiated either from the water-pipes or the brick-work.

In seeking an explanation of these phenomena, it is proper to mention certain conjectures which have been made as to the physiological effects of heat proceeding from different sources. The analogy with light is the basis upon which they rest. Thus it has been suggested that rays of heat from different bodies may have properties corresponding with their refrangibility and rates of vibration. As impressions of color are found to depend on rates of undulation in rays of light, so the various impressions of heat upon the human body may depend upon the rates of undulation in rays of heat.

One reason for the obscurity which still envelopes this subject of the effect of heat upon the human body, proceeds, we believe, from a too exclusive study of the properties of heat as affecting inanimate objects. As we shall have occasion to remark when speaking of the effect of the vapor of the atmosphere, they must both be observed in their influence upon living beings. Because a thermometer, or a hygrometer, gives certain indications, it by no means follows that so complex a machine as the human body is similarly affected.

A thermometer placed opposite a blazing open fire, or a certain distance from a heated surface, whether of iron, soapstone, or porcelain, or in a current of heated air proceeding from a distant source, may in either case mark the same degree, yet everybody who observes at all must feel that they

are distinct kinds of heat. The quantity of heat is the same in all, but the quality, which is a very essential, and perhaps the most essential thing, is an entirely different one. It would seem that a certain degree of luminousness in the source of heat is essential to its best effects.

The belief is very generally entertained among those who feel and complain of the unpleasant effects of anthracite fires, that they are due to dryness of the air. It is also not uncommonly believed that passing air over red-hot iron removes its oxygen as well as its moisture; deprives it, in some way, of qualities essential to the support of respiration, and burns the dust which it contains; that all these things are injurious to health; and that the remedies are found in moderately heated iron and abundant evaporation. We propose, as briefly as possible, to consider these several statements.

Iron excessively heated may finally be burned, and by that process deprive the air in contact with it of a portion of its oxygen. In no other way can its oxygen be removed, and how slow this process is may be known by the number of years required to burn the fire-pot of a furnace, the chief destruction of course going on within and not without.

It is within bounds to say that one pair of lungs will consume more oxygen in a given time than

the heated iron of a hundred furnaces. In so far as oxygen and nitrogen are concerned, a furnace, however heated, has no power to change these gases in the slightest degree, except by burning and consuming the iron in their passage over it.

Excessively heated iron burns the dust with which, in crowded towns, the air is always filled. A stream of sunlight falling in a darkened room will show how abundant this is. It consists of the detritus of every imaginable thing used in our social economy; clothing, food, organic emanations from our bodies and those of the lower animals, shoe-leather, mineral particles raised from the earth, besides the germs of infusorial life concerned in all the processes of putrefaction and decay.

It seems at least probable that the destruction of most of these substances would relieve us from danger, as they are supposed to be agents in the propagation of disease. The part which infusorial life may play in the human economy is obscure; any useful office which it fulfils in the living body is as yet unproved. So far as known its duties are exclusively with dead organic matter.

It has been suggested that the particles of which dust is composed are not burned in their passage over heated iron, but that organic material may be so changed by heat as to give it new properties, the nature of which is unknown, but which may have an injurious influence. It is quite possible

this may be so, but it is unproved. We know that dust so charred has an offensive odor.

Has iron excessively heated any power of abstracting moisture from air passing over it, or any influence upon the vapor of the air differing from that which it receives from iron heated to a moderate degree?

The drying of air by heating it is relative and not absolute. The capacity of air to hold water in the form of invisible vapor, is enormously increased as its temperature is raised. Thus air at 10° above zero, Fahrenheit, will retain 1.11 grains, at 30°, 2.21 grains, at 50°, 4.28 grains, and at 70°, 8 grains to the cubic foot. These are the points of saturation, and any addition of vapor at these temperatures must fall as visible water. Instead of abstracting moisture, heated substances of any sort however heated, and to whatever degree, simply increase the avidity of air subjected to their influence for the absorption and retention of additional amounts.* Theoretically it makes no difference, in so far as the moisture is concerned, whether the air of a room at 65° or 70° has attained this temperature by passing over a long range of pipes

* "The drying of air by metallic stoves is only apparent. The air appears to be more dry because it is hotter, and can, therefore, dissolve more vapor. The higher the temperature the farther it is removed from saturation. If stoves of porcelain or brick do not appear to produce this drying effect it is because they do not heat the air to the same degree." —Peclet "*Traite de la Chaleur*," p. 100, Vol. 3. 1861.

containing water at a temperature of 160°, steam at a temperature where it is condensed into water (212°), or red-hot iron plates at a temperature of 1,000° to 1,500°. Practically, we are prepared to show that this is confirmed by observation.

Seven dry and wet-bulb hygrometers made by Mr. Siefert and carefully compared before being issued, were placed on the 27th January, 1868, in as many different buildings warmed in all the principal modes now in use, viz., hot-water pipes, steam pipes, furnaces for burning anthracite, one furnace for burning wood, and one large room warmed by an open grate burning anthracite.

The object of the inquiry being to ascertain whether the kind of heating apparatus had any influence upon the moisture of the air, and particularly whether iron heated to 1,000° made the air passing over it dryer than iron heated to 160°, no evaporating apparatus was used in any of the seven buildings except the fifth.

These observations were made in the coldest season of the year, and when all the means of warming houses which our climate can demand were required. During the first thirteen days the mercury never rose above 32° and was once observed below zero.

The markings of the dry and wet bulbs were noted at 9 A. M. and 2 P. M., and from them the relative humidity was ascertained by reference to Glaisher's Psychrometrical Tables published in the collections of the Smithsonian Institution.

Record of temperature and relative humidity of the

DATE.	Temperat're of Outer Air.		No. 1, Hot-Air Furnace.				No. 2, Hot-Air Furnace.				No. 3, Hot-Water and Steam Pipes.			
			9 A. M.		2 P. M.		9 A. M.		2 P. M.		9 A. M.		2 P. M.	
	9 A. M.	2 P. M.	Temp.	Humidity.	Temp.	Humidity.	Temp.	Humidity.	Temp.	Hnmidity.	Temp.	Humidity.	Temp.	Humidity.
1868.														
Jan. 27	17	24	65	47	64	51								
" 28	21	25	64	49	65	51					65.5	40	70	40
" 29	25	30	62	50	66.5	55	68.5	49	63.5	49	69	40	69.5	40
" 30	26	25	62	59	67	52	65.5	51	65.5	48	70	40	73	37
" 31	14	26	57	53	69	50	68	44	67.5	43	68	38	72	39
Feb. 1	17	25	59	50	65	49	64.	47	69	45	66	40	70	38
" 2	21	32	64	47	66	53	65	47	66.5	51				
" 3	5	8	62	50	66	52	69	45	65	47	61	39	64	40
" 4	14	25	57	53	66	50	57	47	66.5	43	64	37	69	38
" 5	9	27	63	47	66	50	68	42			78	33	75	37
" 6	27	32	64.5	53	68	53	73	39			79	41	74	45
" 7	18	20	65	52	64	50	69	42	65	44	73	45	68	44
" 8	—2	18	58	44	63	50	64.5	42	64	45	72	45		
" 9	32	40	63	50	67	55	64	44	69.5	47				
" 10	16	16	66	50	68	50	70	47	73	41	64	56	76	41
" 11	11	21	60	50	65	52	65.5	43	64	45	70	45	74	45
" 12	12	26	60	50	65	52	68.5	43	72	41	67	42		
" 13	29	37	62	50	65	52	69	45	70	35	68	44	72	45
" 14	15	17	66	49	66.5	48	69.5	45	71	42	68	42	76	43
" 15	28	39	63	50	63	56	65	49	61	53	68	44	72	45
Mean temp.	17.7	25.6	62		65.7		66.8		67.1		68.8		71.6	
Mean hum'y.				50.1		51.5		45.1		44.9		41.8		41

air of houses warmed in several different ways.

No. 4, Hot-water Pipes.				No. 5, Grate burning Anthracite.				No. 6, Steam Pipes.				No. 7, Furnace burning wood.			
9 A.M.		2 P.M.		9 A.M.		2 P.M.		9 A.M.		2 P.M.		9 A.M.		2 P.M.	
Temp.	Humidity.	Temp.	Humidity.	Temp.	Humidity.	Temp.	Humidity.	Temp.	Humidity.	Temp.	Humidity.	Temp.	Humidity.	Temp.	Humidity.
								65	49	65	49	61	50	66	47
		71	38					65	49	65	49	64	47	59	56
64	42	72	43	66	53	71	47	65	47	65	47	66	47	63	50
69	40	73	43	65.5	48	71	47	64	47	64	47	69	42	65	47
67	40	72	43	61	53	70	49	58	50	59	50	63	44	59	50
69	38	74	38	65	49	69	50	66	47	65	47	65	44	62	47
				65.5	51	68	47	66	44	68	44	67	42	67	47
				64.5	44	70	49	62	44	62	44	69	44	64	42
64	37	71	38	62	49	69	46	61	44	62	44	61	44	63	44
67	49	75	37	64	47	70.5	48	62	44	64	47	59	47	68	40
68	40	72	45	65.5	51	70	49	67	47	70	44	68	44	70	42
64	42	72	43	64.5	53	71	48	60	47	64	47	69	38	62	44
64	37	72	40	64.5	50	66	50	62	44	63	44	62	42	63	42
				69	47	70	51	65	49	66	50	69	42	68	47
61	44	67	40	67	49	70	49	66	47	58	42	67	44	72	41
68	36	71	38	63.5	48	69.5	48	66	42	66	44	61	42	68	40
64	39	71	40	69	47	69	47	64	42	70	42	67	42	62	50
68	40	66	47	67	50	71	52	64	44	64	47	68	50	69	50
67	40	66	47	67.5	47	69	51	65	44	64	42	64	47	68	42
65	42	69	40	66	47	70	49	65	44	68	44	70	47	65	49
65.9	39.8	70.9	41.2	63.1	49	69.7	48.7	63.8	45.7	65.1	45.7	65	44.4	65.1	45.8

The following is a more particular description of the various buildings in which the hygrometers were placed: —

No. 1. A moderate-sized private dwelling-house, warmed entirely by a hot-air furnace burning anthracite. Fire-pot not lined; coal in contact with iron. No evaporating apparatus.

No. 2. A larger private dwelling-house, warmed by a hot-air furnace burning anthracite. No evaporating apparatus.

No. 3. The library of the State House, warmed by hot-water pipes in the cellar until February 5th; on and after that date by steam pipes in the cellar and a few coils in the room. No evaporating apparatus.

No. 4. Library of the Boston Athenæum, warmed by hot-water pipes in the cellar. No evaporating apparatus.

No. 5. A large room (about twenty-two feet square) on first story of a dwelling-house, warmed by a grate burning anthracite. The entry of this house moderately warmed by an anthracite furnace over which from six to eight quarts of water are evaporated daily. No register from furnace enters the room where observations were made.

No. 6. A dwelling-house, warmed by steam pipes enclosed in basement. No evaporating apparatus.

No. 7. A dwelling-house, warmed by a furnace burning only wood. No evaporating apparatus.

The figures in the column headed "relative humidity" show the proportion of moisture held in the air relative to the amount which could be retained at the temperature indicated by the dry-bulb thermometer, *saturation being 100 in all cases.*

It will be seen by the preceding table that the greatest relative humidity, or the moistest air, was found in the house warmed by air which had passed over iron heated to a very high degree,—certainly often during this period to 1,000° Fahrenheit.

The least relative humidity, the driest air, was found in the library of the Athenæum, in which it had passed over pipes heated to a point always less than the boiling-point of water, and usually about 170° Fahrenheit.

The library of the State House (hot-water and steam pipes) was almost equally dry.

Both the libraries were drier than either of the dwelling-houses, and probably for two reasons. The temperature was higher, and the relative humidity diminishes rapidly above a temperature of 65°. Also the absence of cooking operations and of collections of water, such as are found in all dwelling-houses, contributed, no doubt, to the result.

No. 5, the room warmed by an open grate burning anthracite is above the average as regards moisture, but it may have been, and probably was affected by the evaporation of water in the furnace.

Of the four remaining dwelling-houses, the differ-

ences of humidity are only such as might be expected from their comparative size, and from the different number of persons occupying them. No. 1 probably received more vapor from respiration and from culinary operations than either of the others.

Nos. 2, 6 and 7, one warmed by a common anthracite furnace, another by steam pipes, and the third by a wood furnace which was often heated in parts to the point of incipient redness, show almost precisely the same results.

We think the conclusion may fairly be drawn from this record that *iron heated to any point possible in our furnaces has no power to abstract moisture from the air.* Theory and practice in this respect are in perfect accord. Each confirms the other.

In so far as artificial evaporation is concerned it is equally needed with steam pipes* and hot-water-pipes as with fire-pots heated red-hot. If the air of a room warmed to 65° or 68° by hot-water pipes is pleasant, and the air of a room warmed to 65° or 68° by an anthracite fire is unpleasant, in both cases no artificial evaporation being employed, the difference is not in the simple dryness of the air, and must be in something else.

Moreover, if the anthracite-heated room is really made more tolerable at these temperatures by the

* Buildings specially arranged for drying cotton cloth, wood, or other materials, are usually heated by steam pipes.

addition of vapor, as many intelligent persons maintain, it appears to the writer that it must be through some action of vapor as yet unexplained. Certainly the *need* of additional vapor is not felt at these temperatures with radiating open fires of wood or bituminous coal, or with heat derived from hot-water pipes or steam pipes.

The degree of relative humidity which air should possess for healthy respiration has been the subject of much inquiry, and particularly in our anthracite-burning community, where it is no uncommon thing to find the temperature of a room 75° or 80° at a height of five feet from the floor, and ten degrees higher at the ceiling. We believe that a right understanding of this most important subject has not yet been reached, and that some of the difficulties in the solution of the question are to be found in the unfitness of air for respiration from other causes than its condition of humidity. Some of these causes we shall presently refer to. The quality of air in the library of the Boston Athenæum is worthy of the notice and observation of those who are interested in the subject. This air, coming through coils of iron pipes containing water much below the boiling-point, it will be seen by the preceding table is exceedingly dry and yet perfectly agreeable, and its wholesome character when, as is usually the case, it is frequently changed by ventilation, can hardly be doubted.

One reason why the need of special evaporating apparatus in our houses is so much insisted on is a purely theoretical one. The argument is something like this: Air taken from out of doors at the average winter temperature of 28° with a relative humidity of 60 (saturation being 100), contains 1.26 grains of vapor to the cubic foot. Raise the temperature by a furnace so that the thermometer shall be at 68° within the house, and unless water is artificially added the relative humidity will be 17, which is drier than the air of a desert. All this is strictly true, yet practically in our houses it is not so. Water *is* added in all such cases, but the sources of its supply are not obvious. They are found in respiration, in all the numerous collections of water about the interior of houses, in culinary operations, in the stores of water contained in all hygroscopic substances (and almost everything is hygroscopic), and very possibly by the absorption of additional amounts of vapor from the outer air through all the channels concerned in natural ventilation, by windows and doors, and cracks and crannies of every kind. There is, however, in spite of all these means of adding to the relative humidity of heated air, a certain obscurity as to the sources of supply. Thus it is stated by Haller* that experiments carried on over six years with the Meiss-

* Die Lüftung und Erwärmung der Kinderstube und des Kranken Zimmers. Von D. C. Haller, 1860.

ner stove common in Germany, showed that the relative humidity was not lessened at all by moderate warming.

The preceding table gives abundant proof that the relative humidity of air artificially raised fifty or sixty degrees, is not changed in anything like the proportion which would exist theoretically, and which would certainly exist practically if all sources of additional moisture could be excluded.

Another cause of error in reasonings upon this subject seems to be found in overlooking the power of adaptation which man possesses to changed conditions of humidity, as well as to so many other of the circumstances by which he is surrounded.

The human body cannot be regarded as an inanimate hygroscopic substance liable to warp and crack like a piece of furniture. A close analogy may be discovered between the capacity not only to bear, but to enjoy the highest health under extreme alternations of both temperature and humidity. Animal heat is maintained at about 98° whether the temperature of the air is 20° below zero or 100° above. It by no means follows because the air is dry that the evaporation from the human body is in proportion to its aridity, although this no doubt has an effect. But supposing this excessive evaporation were proved, it still remains to be shown that the effects upon health are injurious. A man is in himself a reservoir of water, three-quarters of

his whole bulk being composed of that element; and he is also a great evaporator, giving off by the skin and lungs, according to the best authorities, from 25 to 40 ounces or about a quart of water per day. This exhalation is doubtless controlled, limited, and regulated by the nervous system. Certainly knowing these facts we may at least doubt the expediency of adding the evaporation of water to the heating apparatus in any crowded assembly. A theatre or lecture-room containing 2,400 people is already provided with an evaporating apparatus throwing into the air 25 gallons of water per hour, and under such circumstances the air soon becomes saturated unless frequently renewed. That saturated warm air is exceedingly oppressive is a fact which everybody recognizes in the dog-days of August. Those who have been long exposed to the summer air of the low-lying wet regions of our Southern coast will not need to be reminded of it. On the other hand, the dry air of the interior of the South American continent is reported by Boussingault and others to be exceedingly healthful and agreeable.

Who can say that the dry air of Minnesota is less salubrious than the moist air of Nantucket or Newport? There is no reason to suppose that either is wanting in conditions of humidity favorable to health and long life. The meteorological tables of the Smithsonian Institution enable us to

compare these two regions for 1859. New Bedford, Mass., at 90 feet elevation above the sea, has a mean relative humidity of 80, while Fairfield, Iowa, 940 feet elevation above the sea, has a relative humidity of 61, saturation being 100. In the three winter months, the minimum humidity was often observed at Fairfield as low as 10, and sometimes even 5. The same is no doubt true of St. Paul, Minnesota, so much resorted to by invalids; but of the hygrometry of Minnesota we can learn nothing positive from any reports published by the Smithsonian Institution, although it is understood that they have a mass of observations made since 1859, but not yet reduced to a form for publication.

Evidence of the healthfulness of dry air is also afforded by the experience of arctic voyagers. In those excessively cold regions the air of the cabins of vessels, heated to 60° or 70°, must be as dry as anything which can be found in the world. It is stated by Mr. Steinmetz, an English writer on meteorology, that the wainscoting of the cabin of a ship in the arctic regions sometimes shrinks half an inch in a panel of fifteen inches width. Yet it is well known that the health of crews in the frozen seas is singularly preserved.

In view of this tolerance of air almost devoid of vapor and the ready adaptation of the human system to such extremes, it may be suspected that it would be more reasonable to regard the absolute as well

as the relative humidity of air. Although as before stated air raised from 28° to 68° becomes *relatively* dry, it remains *absolutely* nearly as humid as before; the only difference being in its expansion of volume, which between the points referred to would be only about nine-hundredths of one per cent.

It may be imagined that the human body becomes in the winter months attuned (if the expression may be allowed) to a diminished amount of aerial vapor, and that a single grain to the cubic foot, which is even more than we get in the outer air with the temperature at zero, is in accordance with some general plan of nature whose workings in this respect, as in so many others, are imperfectly understood.

The tolerance by man of air possessing the extremes of humidity is shown on the one hand by the good health of sailors in tropical seas, breathing air very nearly or quite saturated with moisture, 10.8 grains to the cubic foot at 80° Fahrenheit; and on the other hand by the robust and vigorous health enjoyed by lumbermen and arctic adventurers breathing air which, at 10° Fahrenheit, holds but 1.1 grain to the cubic foot. In the latter case we may also suppose that the air is raised in temperature even higher than the tropical air before it reaches the air-cells of the lungs, and supplied with at least ten or twelve grains of vapor to the cubic foot before it is expired. Yet this hydrating

process is performed for an indefinite period without the least inconvenience, if the man is duly supplied with clothing and food.

One of the most marked disadvantages on the score of health attending a very moist artificial atmosphere is from the tendency which is observed in vapor to combine with organic impurities. This fact has been frequently noticed, and is specially referred to by Dr. Parkes, of the Netley School, in his invaluable treatise on Hygiene.* He says: "The most important class of diseases produced by impurities in the atmosphere are certainly caused by the presence of organic matters floating in the air; and from the way in which, in many cases, the organic matter is absorbed by hygroscopic substances, it would appear that it is often combined with, or is at any rate condensed with, the water of the atmosphere."

A familiar illustration of this disposition of organic impurity to combine with moisture, is found in the clothing of a bed which has been occupied, and has thus received the water of perspiration and the organic matters which the body is constantly throwing off, and which readily undergo fermentation. If clothing which has been slept in is bundled up while damp, the odor of decomposing animal matter is retained for a long period.

Having thus entered a general protest against a

* Parkes' Hygiene, p. 91,

humid artificial atmosphere, and stated our belief, and the reasons on which it is founded, that a dry quality of air has many advantages, and is perfectly consistent with health, it remains to be said that common experience shows that a room heated to 70° and upwards at a height of five feet from the floor, becomes more tolerable by the artificial addition of moisture unless it is receiving vapor from the presence of a large number of persons, or from many gas-burners or other modes of lighting. In such a room, when the register is in the floor and the heated air ascends vertically, a thermometer will show the temperature to be very much higher near the ceiling. With this degree of heat there can be little doubt that evaporation from the skin and lungs is really increased, and this in equal degree whatever may be the mode of heating.

Could heat be more equally diffused throughout a room warmed by a register as it is by the radiant heat of an open fire, such temperatures as we now so often encounter in dwelling-houses would not be demanded, and the need of artificial evaporation would not be felt; but in point of fact it is very common to find the carpet warmed only to about 60°, while at the height of the head it is 70°, and at the ceiling many degrees higher. Artificial evaporation also tends to reduce the temperature, a certain amount of heat being abstracted by the conversion of water into vapor.

There are also many persons so constituted that a moist air is more agreeable to their feelings than a dry air, and for the same reasons doubtless, whatever they may be, which would lead them to prefer the climate of Nantucket to that of the interior of the continent.

It should also be stated that in certain inflammatory and irritable conditions of the respiratory organs a warm moist air is of inestimable benefit. It only remains to add that the evaporating apparatus usually placed in furnaces is quite inadequate to produce any effect appreciable by the wet-bulb hygrometer. To change the humidity of the air under good ventilation, a large and shallow pan exposed to the full heat of the furnace and constantly supplied by a cock whose movements are regulated by a ball floating on the water, or else a renewal of the water by pailfuls daily, are indispensable.

Probably the most useful way in which to add vapor to the air of a dwelling-house for those who require it, is by some attachments over the registers, provided they do not obstruct the ingress of air on which both warming and ventilation are dependent. By such adjustments moist air may be thrown where desired, and the inconvenience and discomfort of finding it condensing and dripping from the cold glass of the sky-light may be in part at least avoided.

In apartments *reasonably* heated, by which we

mean a temperature not exceeding 68° five feet from the floor, and with not more than ten degrees difference between floor and ceiling, whether the heat is derived from hot air furnaces, open fires of wood or coal, steam pipes, or hot water pipes, the relative moisture in the winter climate of Boston has been found, in the course of many observations, to never fall below 40 per cent. of saturation. With this amount of unavoidable vapor, *no artificial evaporation whatever is required on the score of health.*

PART II.

If, as we believe, the peculiar effects upon the human system attending the combustion of anthracite are not due to any change in the character of air or its contents by the contact of highly heated iron, or to the abstraction of moisture, we must look next at the composition of this fuel and the products of its combustion.

Anthracite coal is nearly pure carbon. Ure's Dictionary and Professor Bloxam give the analysis of American anthracite as follows:—

Carbon,	92.30	Carbon,	90.39
Volatile Matters,	6.42	Hydrogen,	3.28
Ash,*	1.28	Nitrogen,	0.83
		Oxygen,	2.98
	100.00	Sulphur,	0.91
		Ash,*	1.61
			100.00

The composition of anthracite may be said to differ from that of all other fuel in common use,

* Chiefly silica, alumina, and peroxide of iron.

except charcoal and coke, in the very large proportion of pure carbon and the very small proportion of compounds of hydrogen.

The products of its combustion may be stated to be carbonic acid and carbonic oxide gases, with a small amount of sulphurous acid gas and watery vapor.

Anthracite burns without smoke or soot and almost entirely without flame. When combustion is complete the products are carbonic acid gas and water, and the fumes of sulphur, which although small in amount are often perceived.

Combustion is however seldom complete even in the furnace of a steam-boiler where the heat is intense and small supplies of fresh fuel are constantly added; it is certainly incomplete unless the supply of air passing through and over the fire is abundant. Every one has observed the difficulty in bringing a mass of anthracite in a stove or grate to the point of free and complete ignition, particularly in cold weather.* Owing to the great density of the fuel heat is conducted away from the surface, and such exposed portions can hardly be raised to the temperature required for burning.

We will suppose the fire to be fairly kindled and

* Hard coal taken directly from out of doors in our coldest weather burns very differently from coal which has been kept in a warm cellar or room. In either case heat is lost in bringing it up to combustion point. In the former case the loss is often so great as to put out the fire.

a mass of anthracite thrown over it. The process which follows may be thus described. The actual combustion of the lower range of coal in contact with the fire gives origin to carbonic acid gas. This, rising through the mass of heated coal above, is deprived of a portion of its oxygen and issues from the surface as carbonic oxide gas. In this form it escapes by the flue for a period depending on the activity of the fire and the amount of air admitted. Finally, when the temperature of the mass is raised, if the supply of air is sufficient it breaks into a pale-blue flame signifying its reconversion into carbonic acid gas. This may often be observed on suddenly opening the door of a stove or furnace. Without a supply of air it continues to pass off as carbonic oxide; with a supply of air and a sufficiently elevated temperature it burns and becomes carbonic acid.* Sulphurous acid gas from the combustion of the sulphur is continually given off in small amounts.

The properties of these gases are now to be considered.

The opinions which have for a long time prevailed concerning the poisonous nature of carbonic acid are greatly modified by recent observations.

* Barreswill (Journal für Praktische Chemie, Vol. LXII.) thinks that at low temperatures, carbon is converted into carbonic acid, and at high temperatures into carbonic oxide: and explains in this way the more poisonous influence of a defective flue than of a pan of open coals.

Its singular harmlessness and even its refreshing qualities when received by the stomach in effervescing drinks; the impunity with which considerable amounts can be breathed by the workmen in soda-water factories; its use by Dr. Simpson of Edinburgh as an anæsthetic agent, diluted with two parts of air, — these and similar observations have led many chemists to doubt whether it was by itself, strictly speaking, poisonous. The statements made by physiologists and chemists are still conflicting, but the tendency of opinion is evidently to rank it rather with the obstructors of respiration than with the poisons.

Dr. Taylor says, in reference to this question, "It is absolutely necessary to make a distinction between the contamination of air by the addition of a proportion of free carbonic acid, and the case where this gas is produced by combustion or respiration."*

M. Bernard states that carbonic acid is not poisonous, and that when an animal dies from breathing this gas its death is owing to the mere want of respirable air; hence he considers its action to be purely negative like that of nitrogen; in short that it operates not by poisoning but by inducing suffocation. †

M. Guerard has breathed large amounts of carbonic acid from the expansion of liquefied acid

* Taylor's Med. Jurisp., p. 711.

† Substances Toxiques, p. 137.

without inconvenience. His opinion is that "carbonic acid is rendered more fatal by the presence of carbonic oxide, and that a quantity of each, which if respired alone would be innocuous, may become fatal to life if respired in mixture."*

Regnault † asserts that carbonic acid can be breathed with impunity provided there is sufficient oxygen to maintain respiration. We shall again refer to the action of this gas when mingled with others, but meanwhile it may be said that it seems most probable that it does really possess active noxious properties of its own and that when respired its effect is narcotic. There is an important distinction certainly to be made between carbonic acid and nitrogen, since the former is readily absorbed by the blood. At the same time its most injurious influence is doubtless found in the obstacle which its presence offers to the free escape of carbonic acid by diffusion from the blood of the venous circulation in the lungs.

Concerning the properties of carbonic oxide gas, there is no discrepancy of opinion among physiologists or chemists. It is an active poison, *inodorous*, tasteless, and absorbed by water only in a slight degree.

Leblanc says: "One volume of it diffused through one hundred volumes of air, totally unfits

* Annales de Hygiene, 1843, T. 2, p. 55.

† Taylor's Med. Jurisp., p. 716.

it to sustain life; and it appears that the lamentable accidents which too frequently occur from burning charcoal or coke in braziers or chafing-dishes in close rooms result from the effects of the small quantity of carbonic oxide which is produced and which escapes combustion, since the amount of carbonic acid thus diffused through the air is not sufficient in many cases to account for the fatal result."*

Leblanc analyzed the vapor from burning charcoal which proved fatal to a dog, and found carbonic acid 4.61 parts, carbonic oxide 0.54 parts.

Watts' Dictionary of Chemical Science says: "Carbonic oxide gas is very poisonous, acting chiefly on the nervous system, causing giddiness, sometimes acute pain in various parts, and asphyxia."

A very complete examination of the poisonous properties of carbonic oxide has been made by M. Bernard, Professor in the "College de France."† He says: "Carbonic oxide is one of the most poisonous gases known. For a long time it was supposed that under these circumstances (death by the fumes of charcoal) the poisonous agent was carbonic acid, which in all combustion is produced in considerable quantity. Recently in examining the subject with more care it has been discovered that besides carbonic acid, there is formed in these cases

* Bloxam's Chemistry, and Taylor's Med. Jurisp.

† Leçons sur les effets des substances toxiques.

another very deleterious gas, — carbonic oxide. Carbonic acid was then considered quite innocent by most of those who admitted that in poisoning by the fumes of charcoal the deadly agent was carbonic oxide. We have seen that this is incorrect, and that death may be caused by either of these gases. In the case of carbonic oxide death results from poison; in the case of carbonic acid, from asphyxia."

Many experiments were made by M. Bernard before his class showing the effects of carbonic oxide on the lower animals. The results are seen in the action of this gas upon the blood, by which it is readily taken up through the lungs and passes into the general circulation. He finds the globules of the blood to be paralyzed, in a certain sense, by its presence; that they become unfitted for their office; that the blood remains red; that the conversion of arterial into venous blood is arrested; and that the animal dies as if by prussic acid. When the amount of this gas administered is insufficient to cause death the animal recovers on being supplied with atmospheric air and exhibits no subsequent ill effects.

M. Bernard also confirms the opinion of M. Guerard, before referred to, that the mixture of carbonic acid and carbonic oxide is more dangerous than either respired alone.

Dr. Letheby, Professor of Chemistry in the Medical College of the London Hospital, says "he has

tried the effect of carbonic oxide on birds and young Guinea pigs. An atmosphere having two per cent. of this gas will render a Guinea pig insensible in two minutes, and in all these cases the effects are the same; they fall insensible, and either die at once with a slight flutter hardly amounting to convulsion, or they gradually sleep away as if in profound coma. The post-mortem appearances are not very striking; the blood is a little redder than usual, the auricles are somewhat gorged with blood, and the brain is a little congested."* He also says that "This gas in a more diluted condition is still able to exert an injurious action, and it is very probable that the singular catastrophe which happened at Clayton Moor, in 1857, was caused by the diffusion into the air of carbonic oxide gas from the neighboring furnaces. There is a row of cottages near to these furnaces, where, in the month of June, 1857, a number of persons were seized with insensibility which soon passed in some cases into coma and death. About thirty persons were thus attacked, and six died. The effects were attributed at the time to the escape of sulphuretted hydrogen from the slag on which the cottages were built; but it is more than probable they were caused by the oxide of carbon from the furnaces."

M. Adrien Chenot, a chemist of the French Academy,† relates a case of poisoning by this gas in his

* Chemical News, April, 1862. † Comptes Rendus, T. 38, 1854.

own person. Being anxious to examine the gas yielded by his process of smelting zinc ores, and not having a suitable instrument at hand, he drew a mouthful of carbonic oxide from his furnace by a pipette. While thus holding it he was suddenly struck on the back by an assistant and the gas was inhaled. He fell as if struck by lightning; the eyes were turned back in their orbits, the skin was discolored, the veins were swollen and presented a black tint under the skin, and there were violent pains in the chest. After removal to the open air sensibility gradually returned. Among the effects described, M. Chenot says he felt as if his brain was violently compressed; for several days there was a feeling of depression and languor, difficult digestion, and obstinate and heavy sleep; and for many subsequent weeks a morbidly excited state of the nervous system.

Similar effects are described in the same volume of the "Comptes Rendus" as resulting from the escape of carbonic oxide from a balloon which had been filled by the gas (water gas) produced by the passage of vapor over charcoal heated to redness. The aeronaut nearly lost his life.

M. Chenot also relates several instances in which poisoning resulted from inhaling carbonic oxide when greatly diluted.

The deadly gas thus described is produced abundantly in all ordinary combustion of anthracite.

Its pale blue flame presents an appearance peculiar, distinctive, and not to be confounded with any other. It flickers over our grates, stoves, furnaces, and appears in whatever form anthracite is burned. It is seen at night burning as it issues from the chimneys of factories and steamboats using this fuel. Even the free combustion in such places, where supplies of coal are added every few minutes, is seen to be insufficient to burn and convert it into the comparatively safe carbonic acid until it reaches the outer air.

Does this gas really escape from our grates, and stoves, and furnaces, and mingle with the air we breathe?

Although carbonic oxide is completely inodorous, another gas with which it is mixed is not. If one escapes it may fairly be presumed the other does also. Who of us is not perfectly familiar with the pungent, irritating fumes of sulphurous acid gas, which we are liable to meet with wherever and in whatever form hard coal is burned, whether in open grates, stoves, or furnaces? Perceptible in various degrees, its existence is often denied by those who have been long accustomed to it; for habit dulls the sense of smell in a remarkable degree; but coming from the open air it is often evident enough. Persons subject to spasmodic asthma can perceive it through its effect upon the air-passages. When the draft of a furnace is checked by the sudden cooling

of the flues from the addition of fresh coal it is especially evident. In an open grate with a good draft it is least perceptible; but even here, when the grate is newly filled, it can generally be perceived by putting the face close to the mantel-shelf.

The presence in anthracite of this minute proportion of sulphur is of real advantage in its domestic use, since, like the irritating smoke from wood and soft coal, it warns us of danger, and furnishes a measure, however imperfect, of the amount of poisonous and inodorous material with which it is associated. Without it the combustion of anthracite for warming our houses would be far less safe than it actually is.*

The proof that it escapes into the air-chamber of furnaces is not however dependent upon the sense of smell. Litmus paper placed over the register of an ordinary furnace in which no smell of sulphur may be perceived is in a short time not only bleached but reddened, showing unmistakably the presence of sulphurous acid.

Another kind of proof that carbonic oxide gas mingles with the air of our houses is found in its observed effects; and in this respect it resembles the evidence on which certain green papers have been convicted of conveying arsenic poison to the

* The proportion of sulphur in the different varieties of anthracite is not constant, but the coal commonly used in Boston contains enough to be perceptible as above stated.

air of rooms. Arsenic found in the paper, and a certain train of symptoms corresponding with known effects of arsenic in the bodies of those who breathe the air which has been in contact with the paper; an inodorous, insidious, stupefying, poisonous gas in the grate or furnace, and in the persons of those exposed to its influence peculiar sensations, vaguely associated by experience with the burning of hard coal, but having a remarkable correspondence with the ascertained effects of the inhalation of carbonic oxide. Chemists are not required to find the arsenic in the air to prove the reality of the poison, neither have they yet found the carbonic oxide.* Its discovery in either case when existing in amounts only sufficient to produce the effects observed would be a matter of great difficulty.

It may however be objected that the air of the room is directly exposed to arsenic poison, while the poison of carbonic oxide is safely conducted up the flues and out of the house. That it is so conveyed for the most part is certainly true, or we should none of us be living to consider the question; but that a portion is also thrown into our houses may be shown by other reasons than those derived from its observed effects or from its association with the fumes of sulphur.

An open grate burning soft coal throws into the room particles of soot as all house-keepers know.

* It has been observed since this was written. See Appendix.

An open fire of wood communicates to the room a peculiar flavor of acetic acid, and often a trace of pungent smoke.

In both cases the amount of these matters is determined by the completeness of the draft, the state of the weather, the way in which the fire is built, the opening and shutting of doors, and a variety of similar conditions familiar to everybody. There is no reason why the poisonous gases from anthracite burned in a grate, although invisible, should not escape with equal freedom and from the same causes. There is even more reason to expect it since modern flues for using this coal are frequently made only eight inches in diameter. This size of flue stands in no proper relation with the air-space exposed in front of the fire; and consequently a considerable amount of air being drawn within the range of such a fire and receiving a portion of the products of combustion, fails to find egress and flows in part over the mantel-shelf.

Cast-iron stoves and furnaces are necessarily made in pieces, and these pieces must separate with the expansion and contraction of the metal.

No fastenings can resist this power, and some of the makers of furnaces recognize the fact by making the pieces to simply rest upon each other in grooves filled with sand or with some other material not firmly fixed to the iron. As these parts are sub-

jected by the application of heat to continual change of form, some portions being also exposed to greater heat than others, they are warped, the fittings become loose, and openings are left through which the products of combustion leak into the air-chamber.

How many furnaces, new or old, would prove to be water-tight in the fittings of their parts, supposing them to be put to such a test? Yet in the way furnaces are often used to save coal and superfluous heat, the dampers partly closed, or, which is the same thing, air admitted to the funnel between the fire and the flue, a very slow and imperfect combustion going on, and the gases within the fire-pot nearly stagnant, nothing short of water and air-tight fittings can prevent an escape from taking place between the joints.

Cast iron is also frequently defective in its structure, and this is so well recognized a fact that the most rigid tests are required before it can be used for many of the purposes to which it is applied. Cast-iron tubes for the conveyance of illuminating gas are subjected to very heavy pressure before they can be safely used by the gas companies. It is quite as important that our anthracite-burning stoves and furnaces should be examined for the discovery of imperfections with equal care; but that they are so in all cases may at least be doubted.

Wherever and however an opening exists, whether by imperfect fittings of the parts or by defects in the

asting of the iron, the law of diffusion of gases must operate to mingle the contents of the fire-pot, furnace, and smoke-pipe with the external air unless the current passing up the flue is very active.

But independent of the law of diffusion of gases there is an obvious mode of escape through any cracks or openings existing in any part of a furnace enclosed in a brick air chamber. Within this brick work two currents or draughts are in constant operation and exerting their influence upon every part of the iron pot, radiator, drum, pipe, or other form of iron so enclosed. One of these currents passes through the fire and escapes by the flue. The other current, which passes around the iron, enters beneath or around the furnace and escapes in the rooms to be warmed.

When the interior current is strongest fresh air enters from the air chamber by any crack or crevice however small which may exist, and passes up the flue; but whenever the exterior current is strongest this passage is reversed and the products of combustion are drawn into the air chamber and escape into the house.

This may and doubtless does occur to a greater or less extent whenever in cold weather with a violent current passing up the registers, the draft of the chimney is checked either by closing dampers, or by cooling the flue by the admission of fresh air

beyond the fire, or by the addition of a large amount of fresh coal.

It may be remarked that old cast-iron furnaces of whatever form or pattern are more offensive than new ones. An old furnace is discarded and a new one of a different pattern substituted, and the conclusion drawn from its better working that there is a real improvement in its form. The real advantage is generally in the more perfect fitting of its parts, an advantage lost for the most part in a single winter's use.

But it is not even essential to prove that iron stoves and furnaces permit the passage of gases through their joints and fittings or through defects in their casting. A surprising discovery has quite recently been made in France which has a most important practical bearing upon the question we are considering. MM. St. Claire Deville and Troost, of the French Academy of Sciences, have published in the "Comptes Rendus" an account of their experiments upon the permeation of metals by gases, from which it appears that several metals, including iron, when heated to a dull red heat, permit the passage of gases directly through their substance, and this by virtue of a property thus described: "In metals the porosity results from the dilatation which heat induces in the intermolecular spaces. It is related to the form of the molecules, which we may suppose to be regular, and with their '*alignement*,'

which determines the cleavage or the planes of fracture among crystallized masses." *

It will be observed that this theory of the phenomenon harmonizes perfectly with the new philosophy of heat as explained by Professor Tyndall, in his "Heat a Mode of Motion." Of the fact of the penetration of metals by gases, abundant evidence is presented.

The first of the articles by MM. St. Claire Deville and Troost is entitled, "Upon the permeability of iron at high temperatures."† It is here shown that heated cast iron permits the passage of hydrogen gas; the tubes through the walls of which it freely passed were of the thickness of from three to four millimetres, or about one-seventh of an English inch. The second communication on the same subject is entitled, "On the passage of gases through solid homogeneous bodies." ‡ The following is an extract: "I am able to demonstrate to physicists the great interest which attaches to these experiments upon substances as perfect as iron and platinum. These bodies resist elevated temperatures; their feeble conductibility facilitates very much the construction of apparatus; they are not permeable at ordinary temperatures, but this property develops as they are heated. As these

* Comptes Rendus, T. 57, p. 965, 1863.
† Comptes Rendus, T. 57, 1 63.
‡ Comptes Rendus, T. 59, 1864.

substances are homogeneous the phenomena which they exhibit are free from disturbing causes such as attach to experiments upon materials obviously porous."

In seven experiments which are minutely described, hydrogen, nitrogen, and *carbonic oxide* gases passed readily through the walls of cast-iron tubes three millimetres (about one-tenth of an English inch) in thickness.

The experiments of the French chemists are confirmed in all essential points in England by Prof. Graham, F. R. S., Master of the Mint. Our immediate and practical concern is with the penetration of iron by carbonic oxide and carbonic acid gases. It appears that it is by reason of this property that iron is converted into steel.

The comments of Prof. Graham upon this penetration of iron by carbonic oxide are as follows: —

"Pure iron is then capable of taking up at a low red heat and holding when cold, 4.15 volumes of carbonic oxide gas. This fact, confirmed in various experiments, explains partly, if not entirely, the abundance of carbonic oxide observed among the natural gases of iron in several experiments of MM. Deville and Troost. In the course of its preparation wrought iron may be supposed to occlude six or eight times its volume of carbonic oxide gas which is carried about ever after. How the qualities of iron are affected by the presence of such a

substance, no way metallic in its characters, locked up in so strange a way but capable of reappearing under the influence of heat at any time with the elastic tension of a gas, is a subject which metallurgists may find worthy of investigation. The relations of the metal iron to carbonic oxide gas appear to be altogether peculiar. They cannot fail to have a bearing upon the important process of *acieration*. . . . .

"The inquiry suggests itself whether acieration would not be promoted by alternation of temperature frequently repeated. The lowest red heat, or a temperature even lower, appears to be most favorable to the absorption of carbonic oxide by iron, or for impregnating the metal with that gas; while a much higher temperature appears to be required to enable the metal to decompose carbonic oxide, to appropriate the carbon and become steel."*

It clearly appears from the experiments of MM. Deville and Troost, and the remarks of Prof. Graham, that iron at a low red heat, or even lower, can take up this most deadly poison from our anthracite coal and permit its passage directly through the substance of the metal.

Does this not offer a reasonable explanation of the injurious influences of our iron stoves, furnaces, and smoke-pipes, when excessively heated?

These influences are real. It cannot be mere

* London Philosophical Magazine, Vol. XXXII., 1866.

imagination which has so generally associated highly heated iron with unpleasant and peculiar sensations; yet the connection has been mysterious. To say that air is scorched is vague and indefinite. The component parts of air are certainly unchanged; the oxygen, nitrogen, and watery vapor remain as before. The dust in the air is, or may be, charred or even burned; but is it at all probable that the charring or the complete combustion of minute amounts, hardly perceptible by the sense of smell, of the substances of which dust is composed, even if it took place in the still air of an unventilated room, could give rise to a *peculiar form of headache, to languor, oppression of respiration, and general disturbance of nervous functions?*

We have seen that there *is* an agent capable of producing these effects; that carbonic oxide always produces them when inhaled; that carbonic oxide is formed in all combustion of anthracite; that it is liable to escape in several ways from the grates, stoves, and furnaces in which it is burned; and that as these latter are commonly used it can hardly fail to escape in greater or less amounts; and that sulphurous acid, an irritating gas and readily recognized, is known to escape.

We therefore feel justified in expressing our conviction that the inhalation of small amounts of this active blood-poison, *carbonic oxide gas* (mingled no doubt with carbonic acid gas, and its poisonous

quality thus increased), is the chief and probably the only cause of the unpleasant sensations and the injurious influences so commonly associated with the combustion of anthracite coal.

PART III.

THE conclusions at which we have arrived are certain to be met by the objection that if we are habitually breathing a deadly poison as surely fatal as prussic acid, its effects would be more obvious than they are found to be. The objection is in the nature of negative evidence, but it has force, and must be explained. Burn charcoal or anthracite (both nearly pure carbon) in a room without a flue, and close the doors and windows, and death is the inevitable result to the occupant in a very short time. There are many instances on record where a partial escape of the products of the combustion of both charcoal and anthracite have been fatal, and very many where serious illness has been thus caused.

In our furnaces the escape of carbonic oxide is comparatively small. As we have previously pointed out it is fortunately signalized, when considerable in amount, by the well-known odor of sulphur, and this alarms the family in season to prevent immediate and marked effects.

But there is established in those who are accustomed to breathe air mixed with carbonic oxide a certain tolerance of, and insensibility to its noxious influence, and in this respect it closely resembles the operation of other active poisons. Many of the narcotics have this property, although it is not confined to this class of toxical agents. The power of habit in modifying the effects of opium is so well known that it need only be referred to. Among the inorganic poisons, arsenic may be taken in gradually increasing doses without very perceptible ill effects until an amount is daily swallowed which would kill a beginner.

Women have been known to take arsenic for the improvement of the complexion; and in parts of Austria people eat it habitually. It is none the less an active poison for all this, and its use as well as that of opium, if not immediately fatal, is certain to render the body less capable of resisting disease, and to shorten life.

We believe that a similar tolerance of the poison of carbonic oxide gas is established in those who habitually breathe it; that this tolerance is in great measure, and probably completely lost during the summer months, and that every winter it is again gradually acquired. It is a common rule among people of intelligence and observation that starting the anthracite furnace for the winter is to be postponed till the latest moment; not until actual suffer-

ing from cold compels it is its headache-producing heat permitted as the least of two evils. It is not so with fires of wood or soft coal; they are enjoyed in early autumn.

Once fairly established the furnace makes everybody, while enjoying the heat, more or less uncomfortable from an ill-defined sensation of oppression, headache, and nervous disturbance.

This, however, diminishes from day to day, the capability of distinguishing and analyzing these effects is lost, and in a short time the system becomes accustomed to the poison as the Hungarians become accustomed to arsenic, or the Turks to opium.

The character of the air under these circumstances is painfully felt by those in whom this tolerance is not established. To those who have recently come from Europe where other kinds of fuel are burned, to those who have lived much in the open air, and in fact in greater or less degree to all who have not been through the process of seasoning required to produce insensibility to its effects, it is distressingly evident.

It need not excite surprise that these effects are not universally recognized when we remember the general indifference to ventilation, or the removal of air made foul by respiration and combustion, which prevailed everywhere not many years ago.

In all places of public assembly, wherever crowds were collected, whether in theatres, court-rooms, halls, or churches, the absence of fresh air was the rule. It is bad enough now, but the need of ventilation is recognized in theory, and sometimes in practice. The audiences at some of our new theatres enjoy and appreciate the luxury of warm and fresh air, and will never again forget its advantages, or be willing to exchange it for what they formerly thought was good enough.

Every part of our social economy is now undergoing scrutiny, revision, and reform, and the safe and healthful method of warming our houses will not linger far behind that of the ventilation of places of public assembly.

If we are asked to say what special diseases owe their origin to the habitual inhalation of the poisonous product of the combustion of anthracite the answer cannot be a perfectly definite one. The processes affecting human health are too intricate to allow us in the present state of chemistry and pathology to point out with absolute precision where the chains of healthy action are interrupted, and to exactly what lesions or permanent disturbances they lead. This much we know; the impression of the poison of carbonic oxide is first received by the blood, whose readiness to undergo the change of character involved in the process of respiration, is impaired, as

shown by the experiments of Bernard.* The brain and the whole nervous system are thence necessarily affected. To these two causes are referable the difficult breathing and the headache. A peculiar suffusion of the face, having somewhat of a livid and congested character may also sometimes be remarked. Beyond this we are not perhaps authorized to trace specific effects. † But are not these enough to show the unwholesome and pernicious influence of this insidious poison even in minute amounts? Disturbances of nervous function of the most varied and obscure character are unfortunately very prevalent among us, and a clue to the cause of some of them may be afforded by the dangers we have pointed out.

Moreover we believe that, surrounded as we are by morbific influences of every sort growing out of the impure condition of air, water, and food, but

* A very clear account of an examination of the blood by spectral analysis in a case of poisoning by coal vapors, is given in the Edinburgh Medical Journal, January, 1868, by Dr. Maclagan. See also the recent statement of Dr. Thudicum in Appendix.

† The appendix contains a reference by General Morin to the communication of Dr. Carret of Chambery. Dr. Carret thought that an epidemic in his Department might be traced to the use of cast iron stoves. It appeared that this epidemic bore a strong resemblance to typhoid fever, and was so regarded by a majority of the physicians who had to deal with it Without pretending to decide this disputed question, it may be permitted us to remark that all modern investigations go to show that the typhoid poison is of organic, and not of inorganic origin; that its causes are to be found in the decomposition of organic material; in air and water rendered foul by putridity.

particularly of air and its contamination by all the processes of society in crowded communities, the human body is the better able to resist their attacks when the seemingly trifling, but constantly recurring causes of temporary loss of vital force are systematically and intelligently avoided.

Having thus pointed out some of the dangers to health which pertain to the more common modes of heating the air of dwelling-houses, it remains for us to show, in so far as this may be done, how they may be avoided.

The best and safest modes of heating now practised are undoubtedly those in which air, drawn from without, is passed through coils of pipes filled with either steam or hot water in an enclosed space in the cellar, and thence distributed above. The disadvantages of this system are, first and chiefly, the expense of establishing the apparatus, which is such as to limit its use to the rich. Another objection to the hot water system is found in the time required to raise the whole body of water to the temperature necessary for the effective radiation of heat. With both steam and hot water pipes great care is required in the coldest weather of our winter to keep up the fire, since if this is suffered to go out while the pipes are exposed to the fresh blast of external air, there is danger of their freezing. This accident, which can only occur through negligence, has frequently happened with hot water apparatus to the

serious loss and inconvenience of the occupants of the house.

On the score of health, both hot water and steam pipes, used in the manner before described, and *not by direct radiation in the room to be warmed*, are entirely unobjectionable. They give an abundant supply of fresh air, moderately warmed, and with no risk of contamination from the products of combustion.

Furnaces for burning bituminous coal are not now used in the Eastern States. They are extensively used in certain parts of the country where this fuel is cheap and abundant, but of their practical working we have no means of judging.

Furnaces for burning wood are much used in the interior of New England and in Canada. They are simple in construction, and give an abundance of heat of the most agreeable quality. They are easily managed, will burn much or little fuel, and respond at once to the fire when it is kindled. The disadvantages attending their use are, first, the need of abundant cellar or yard-room for the storage of wood; second, the addition of fresh fuel four or five times a day; third, the need of a large old-fashioned flue to carry off the smoke, a modern sized flue requiring frequent cleaning; and fourth, the condensation of the products of the distillation of wood, impure acetic acid, in and about the flue and chimney.

Anthracite coal is so convenient a fuel, and gives

such abundant heat, that its continned general use seems to be inevitable. Iron as a material in which to burn it has also so many recommendations that its employment can hardly be dispensed with. If then we are to continue to employ iron stoves and furnaces for the combustion of anthracite, the question is how to use them with safety to health and with economy of fuel.

In theory these two all important considerations of health and economy are in perfect harmony.

Carbon, or hard coal which is almost entirely carbon, completely burned, gives rise to products which are comparatively harmless, and with the evolution of great heat.

Carbon incompletely burned gives rise to products in the highest degree dangerous to health, and with the evolution of a far inferior degree of heat.

By burning anthracite with the production of carbonic oxide, and allowing it to pass away in that form and unconverted into carbonic acid, we lose heating power in a very striking degree.

Carbonic oxide gas, which may be conveyed through the chimney flue at a low temperature, giving the impression that all heat has been extracted and made available, is really *fuel*, and by parting with it in this form it is as truly wasted as if a certain portion of the coal were thrown out of the window. How great this portion may be will appear by the following extract from the "Manual of In-

organic Chemistry," by Professors Eliot and Storer, 1868, p. 361:—

"Furnaces are sometimes seen consuming fuel under such conditions that all the carbonic oxide produced within them escapes unburned into the chimney. In such cases more than two-thirds of the amount of heat which the fuel is capable of yielding must necessarily be lost: for while 1 gramme of charcoal gives off in burning to carbonic acid 8080 units of heat,* 1 gramme of carbon in burning to carbonic oxide gives off only 2473 units of heat. The number last given is determined as follows. It has been found by direct experiment that 1 gr. of carbonic oxide on being burned to carbonic acid yields 2403 units of heat. Carbonic oxide is composed of one atom of carbon weighing 12 and one atom of oxygen weighing 16—the weight of the molecule of carbonic oxide being consequently 28. In one gr. of carbonic oxide, therefore, there can be only $\frac{12}{28} = 0.4286$ of a gramme of carbon; but $0.4286 : 1 = 2403 : x = 5607$, whence it appears that there is evolved by one gramme of carbon in carbonic oxide 5607 units of heat when this carbon unites with the additional oxygen to form carbonic acid; and the difference between this number (5607) and the number (8080) denoting the amount of heat given off by one gramme of charcoal in burning to

* A unit of heat is that amount of heat which will raise 1 gramme of water from 0° centigrade to 1°.

carbonic acid, will show how much heat is evolved by one gramme of carbon burned to carbonic oxide: $8080 - 5607 = 2473$, as above stated."

It thus appears that the loss of heating power when carbon is burned to carbonic oxide and escapes from the stove or furnace in that form is 67 per cent. The loss of health cannot thus be expressed in percentages; but if, as we believe for reasons previously given, this poisonous gas does not all escape into the chimney, there are two motives as strong as can possibly exist for preventing its formation.

The important practical question now is whether anthracite coal can be so burned as to invariably resolve itself either mediately or immediately into carbonic acid. Its extreme density is the obstacle to be overcome. Innumerable efforts have been made, as a measure of economy in the interests of the arts, to effect this complete conversion; but thus far with doubtful success. One mode proposed by which its complete combustion shall be within the power of the operator is by throwing the anthracite upon the fire in the form of fine dust mingled with air, and by a mechanical power. How far this process is successful we are not in a position to judge; and it is here referred to simply as an illustration of the difficulties in the way of its accomplishment.

The various arrangements of inventors and man-

ufacturers for accomplishing complete combustion in stoves and house-furnaces are ingenious and praiseworthy, and all contrivances by which it can be done in any considerable degree are to be welcomed in the joint interest of health and economy. Among many plans the following are most noteworthy: the furnace of Mr. Amory, which provides for the projection of heated air beyond the fire; the furnace of the Earle Stove Co., which admits air for supporting combustion through numerous perforations in the walls of the fire-pot; the "base burning" stoves and furnaces, which provide for the constant and very gradual addition of coal, which is heated before it reaches the place where it is burnt, and falls upon the fire by its own weight as room is made for it. We do not feel called upon to express an opinion as to the comparative merits of these plans. They are all to be commended as movements in the right direction. But the problem is a hard one to solve, and it is this—How to regulate and control the supply of fuel and the supply of air, the latter to be delivered at the very point of combustion, to every furnace under the variable atmospheric conditions to be met with in our climate; conditions of extreme cold alternating with a moderate temperature, high winds and calms, high and low barometer, dry air and moist; and all this to be done through

such intelligence as may be met with in those who feed and regulate the fires. *

Whenever on suddenly opening the door of a furnace a blue flame breaks over the surface of the coal, we may be sure that carbonic oxide has been escaping unconsumed. Whenever any considerable amount of fresh coal has been added, the same imperfect combustion can hardly be avoided. At other times the escape of unburned carbonic oxide will vary with the intensity of the fire, and the amount of air supplied at the very point of combustion.

In view of the danger to health which seems to us, in a greater or less degree, to attend the use of all cast iron furnaces burning anthracite, the following rules are suggested for their management:

1st. To use firebrick or soapstone in contact with the fire, and never allow the fire-pot to get red hot.

2d. To have perfect castings, and as few joints as possible; and these joints should be horizontal and not vertical.

3d. Never to cut off the supply of air to the

* For such reasons we cannot but hope that the time is coming when all this cumbrous machinery for supplying warm air to our houses will be superseded; when it will be no longer necessary to bring in the crude fuel and burn it with so much care and trouble; when either warm air heated elsewhere may be turned on as required, or when the products of the distillation of fuel in either a liquid or gaseous form may be burned, in the exact amounts needed, in some simple apparatus provided with a means of escape for the carbonic acid and watery vapor. Even now illuminating gas may be so used; the only difficulty is the cost.

fire, and never to check the free escape of the products of combustion to the chimney by dampers, or by cooling the flue by the admission of air between the furnace and the chimney.

4th. To so burn the coal that under all possible circumstances a pressure of air from without inwards may be exerted upon the fire-pot, radiators, and smoke pipes.

It is evident from what has been said, that we believe it impossible to burn hard coal in house-furnaces without the production of unconsumed carbonic oxide gas in greater or less amounts. What then is the very best thing to be done if iron stoves or furnaces are to be used? Clearly the best and safest and most economical plan is to convert as much of the fuel as possible into carbonic acid: and then to protect ourselves against the poisonous remainder by using such material for securely enclosing and conveying it away as will not permit of its escape either through cracks, joints, or the substance of the material itself.

During the past few months several interesting suggestions bearing upon this point have been made by different persons whose attention has been drawn to the subject of this treatise. One of these suggestions, made by several intelligent persons without intercommunication, is to the effect that Russia sheet iron, (rolled iron covered with a siliceous glaze), when used as an outer covering

for stoves has been found to give a more agreeable heat than cast iron, and that when pyramidal stoves in this material were in common use there was less suffering from headache than since cast-iron has been generally substituted.

But a more definite experiment has been made at the "Massachusetts Asylum for the Blind" at South Boston. The Superintendent, Dr. S. G. Howe, writes as follows under date of March 12, 1868:—

"I was long ago impressed by the idea that the pupils of this institution suffered in some way from noxious gases evolved in the combustion of anthracite, and took measures to prevent this as far as possible. I changed the construction of the furnaces, and burnt coal in a grate in the centre of a *wrought iron* cylinder five feet in diameter, bolted, and made steam tight; the size of the cylinder makes it impossible to raise the temperature of the iron to a very high degree. I thus acted empirically, without understanding the principle which you elucidate scientifically. The furnaces certainly act much better than the old ones; better indeed than any anthracite furnaces that I know; and there is no sensible inconvenience from the escape of gases."

This experience is most instructive, and almost leads us to believe that a complete remedy has been found for the escape of gases from anthracite furnaces. The only doubt which remains is in the

absence of direct proof that wrought iron is impermeable to gases. The French and English experiments conclusively show that cast iron is freely permeable, but they have not shown that wrought iron is impermeable. We are led to infer it, however, from the constant reference to cast iron as exhibiting this property, and from the explanation offered that it is due to its crystalline structure. We seem at any rate justified in believing from the whole tenor of these experiments, that if wrought iron is permeable it is so in a degree far inferior to cast iron.

In the "Manuel pratique du chauffage et de la ventilation," Paris, 1868, by General Morin, the author, after speaking of the porosity of cast iron and the danger to health from the use of this material for stoves, says: "Stoves of porcelain or of wrought iron, are much to be preferred and have have not the same disadvantages."

For all modes of escape for the gases of combustion through cracks, joints, and the various ways in which visible openings may be caused by unequal expansion, wrought iron, when bolted and made steam-tight, would appear to be a complete remedy. One of the cylinders which had been used for many years at the "Asylum for the Blind," was recently removed to give place to one of still larger dimensions, and was found free from all defects, and apparently as good as when first set up.

Iron of any kind will expand by heat and contract by cold, but wrought iron is an elastic material and will bend before breaking. A furnace of wrought iron, in whatever form it may be made, if its parts are firmly joined like those of a steam boiler, will expand and contract in its whole mass, and can leave no visible opening for the escape of the products of combustion, unless it should be at the point where it rests in the masonry. A wrought iron base would remedy even this possible defect.

From such considerations it would appear that when anthracite is burned in an iron furnace we can hope to succeed in enclosing, and securely holding the poisonous product of imperfect combnstion until it can be safely conveyed away, by making the furnace of *wrought iron plates riveted together as tightly as those of a steam boiler, so that the whole apparatus shall be practically of one piece.*

APPENDIX.

(Translation from the "Comptes Rendus de l'Academie des Sciences.")

PUBLIC HEALTH.

NOTE ON THE SUBJECT OF THE RECENT EXPERIMENTS, BY M M. H. ST. CLAIRE DEVILLE AND TROOST, ON THE PERMEABILITY OF CAST IRON BY GASES.

BY GENERAL MORIN.

The Academy has doubtless not forgotten that in 1865, our late associate, the lamented Velpeau, communicated some observations made by Dr. Carret, Surgeon-in-chief of the Hotel Dieu at Chambery, on occasion of an epidemic which manifested itself in different parts of the Department of Haute-Savoie, and particularly at the College of that city, in buildings heated by cast iron stoves, whilst in the same localities the houses furnished with porcelain stoves were completely exempt.*

Since that communication was made I have abstained from all comment upon it, but subsequent reflection upon the curious experiments, by which MM. Deville and Troost have proved the permeability of iron heated to a high degree by gases, have

* Since his communication to the Institute, Dr. Carret has addressed to the "Minister of Agriculture, Commerce and Public Works" a memoir, rich in facts bearing upon the unhappy influence which the use of cast iron stoves exercises upon the public health. In this memoir the author arrives at the conclusion that cast iron stoves, in permitting the passage through their walls of carbonic oxide gas, are the direct cause of very serious results. He furnishes numerous, and varied, and unquestionable instances.

led me to think that these facts might explain the insalubrity of cast iron stoves heated by pit coal, of which the use is too general in schools, colleges, barracks, guard-houses, and in a great number of public and private establishments.

I therefore requested MM. H. St. Claire Deville and Troost to make, upon an apparatus similar to the guard-house stoves, experiments which would conclusively show the degree of permeability of cast iron heated to a high temperature by the gases resulting from combustion.

By the aid of such apparatus, these accomplished chemists have not only put beyond doubt this question of permeability, but they have determined the proportions of carbonic oxide gas which pass through a given surface of a cast iron stove, as well as that which the metal absorbs and retains.

The importance of these results for the public health is so evident that for this reason they should be known and examined in detail. This I propose to do in a subsequent paper, leaving to the more competent hands of MM. Deville and Troost other deductions useful to science which are involved in the facts referred to.

EXPERIMENTS UPON THE PERMEABILITY OF CAST IRON BY THE GASES OF COMBUSTION, BY MM. H. ST. CLAIRE DEVILLE AND TROOST.

General Morin has done us the honor to ask for an exact analysis of the air which circulates about a cast iron stove strongly heated. We have found that this air contains notable amounts of hydrogen and carbonic oxide gases. This fact is perfectly explained by the permeability to gases which we have previously discovered as a property of iron highly heated, and by the power which Mr. Graham has shown this metal to possess of absorbing carbonic oxide. It also appears that air which has been in contact with cast iron surfaces strongly heated may become harmful to respiration.

It is for this reason that we now publish these remarks, at the same time that we refer to General Morin the result of our

analysis. Our object was to discover whether the porosity of cast iron permitted the gases of combustion to pass through the walls of cast iron stoves, and diffuse themselves in the atmosphere so heated.

The apparatus which we employed for this purpose was chiefly a cast iron stove furnished us by General Morin. This stove, similar to those used in guard-houses, is composed of a cylinder which communicates with the exterior by two openings; the one lateral, permits the passage of air under the grate; the other, above, communicates with the smoke-pipe. By this latter opening the combustible, whether it be coke, pit-coal, or wood, is introduced and falls upon the grate placed above the lateral opening.

The stove in question was heated at different times in various degrees, from a dull red to a bright red heat.

It was surrounded by an envelope of cast iron resting in grooves, connected with the stove above and below, forming a chamber having no communication with the external air except by the interstices remaining in the grooves between the envelope and exterior of the cylinder.

To ascertain the nature of the gases which could pass from the stove to its envelope we employed the following apparatus.

The gases drawn into the enveloping chamber were sucked by a metre placed just beyond the absorbing apparatus. They were first freed from the carbonic acid and vapor of water which they contained by passing through U-tubes filled with fragments of pumice stone, saturated with concentrated sulphuric acid and caustic potash. When thus purified, they were passed over oxide of copper heated to redness. The hydrogen and carbonic oxide were thus transformed into the vapor of water and carbonic acid. To determine these substances they were passed through weighed tubes containing, the first, pumice stone, saturated with concentrated sulphuric acid; the second, caustic potash or baryta. The gases then passed into the metre, which drew them through the whole apparatus, measured them, and then threw them out into the air of the room.

The results reached are contained in the following table:—

This table (p. 75) shows that the gases of combustion pass through the walls of a cast iron stove heated to a dull red or a bright red. These results are explained by the porosity which we have previously found to exist in iron, and in a still greater degree in cast iron. *

The experiments of Mr. Graham have also shown, since our experiments of 1863, that iron absorbs when heated to redness 4.15 its volume of carbonic oxide when exposed to an atmosphere of this gas.

Carbonic oxide, absorbed in our stoves by the interior surface of the cast iron, diffuses itself from the exterior surface into the atmosphere, and this process goes on continuously; hence the "*malaise*" which we experience in rooms heated either by cast iron stoves, or by air heated in contact with red hot plates.

January 20, 1868. General Morin requests the Academy to appoint a commission to examine the subject of the communication of M. Carret, viz., the influence of the use of cast iron stoves upon health.

The following members were appointed:—

MM. Payen, Morin, Fremy, H. St. Claire Deville, and Bussy. (M. Claude Bernard was subsequently added.)

February 3, 1868. General Morin presents the following note in the name of the commission charged with the examination of the communication of M. Carret upon the hygienic objections to the use of cast iron stoves: "The facts presented in the paper of Dr. Carret have appeared to the committee so important with respect to the public health that they think it proper to institute experiments which will present the matter in many points of view." They have therefore accepted the proposition which I have made to them to organize a series of experiments, of which I have presented a general plan, at the "Conservatoire des Arts et Metiers." The result of these researches will be communicated to the Academy.

* We have not found tubes of cast iron capable of maintaining a vacuum.

Numbers of Experiments.		1	2	3	4	5	6
Duration of Experiments.	h m.	6	18—5	7—27	21	12—30	27
Volume of Air drawn through apparatus.	lit.	90.	270.	100.	213.	183.5	251.
Average Temperature of Air in the Metre.	°	25.	23.5	22.4	26.	26.3	23.8
Average Atmospheric Pressure.	m. m.	757.	760.	764.	763.4	762.6	764.
Average volume drawn through per minute.	lit.	.250	.250	.230	.170	.186	.155
Vapor of water collected by the oxide of copper.	mgr.	72.	61.	19.	117.	25.	147.
Proportion of Hydrogen in 1000 lit. of air.		1.072	.303	.250	.786	.230	.785
Carbonic acid collected after passing oxide of copper.	mgr.	125.	658.	79.	208.	57.	68.
Carbonic oxide calculated from the carbonic acid in 1000 lit. of air.	lit.	.710	1.320	.430	.520	.220	.141
Total volume of the two gases in 1000 litres of air.		1.782	1.623	.680	1.256	.450	.925

[The tenth annual report of the Medical Officer of the (English) Privy Council, 1868, contains the valuable researches of Dr. Thudicum, intended to promote an improved chemical identification of diseases. In speaking of the changed condition of the blood, recognizable by spectral analysis, after poisoning by carbonic oxide, Dr. Thudicum says, "It has long been known that carbonic oxide produces a particular change in the color of the blood, which is not destroyed by mixture with oxygen. It was shown that this was due to a combination of carbonic oxide with hematocrystalline, which is always found when these bodies come in contact. The carbonic oxide displaces oxygen, and remains attached to the hematocrystalline, even in its crystals. Upon the fixity of this combination, therefore, depends the fatal effect of carbonic oxide when inhaled for any length of time. Further, by the fixity of its spectrum can the compound be recognized, and consequently poisoning or suffocation by carbonic oxide or charcoal vapor be diagnosed. The carbonic oxide blood has a more bluish tinge than the venous or arterial."]